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A Primer on Applying Monte Carlo Simulation, Real Options Analysis, Knowledge Value Added, Forecasting, and Portfolio Optimization

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by

Dr. Johnathan Mun, Professor

Dr. Thomas Housel, Professor

Graduate School of Operational and Information Sciences

Naval Postgraduate School

Prepared for: Naval Postgraduate School, Monterey, California 93943

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Naval Postgraduate School
Monterey, California

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The report was prepared by:

____
Johnathan Mun, Ph.D.
Professor, Graduate School of Operational and Information Sciences

____
Thomas Housel, Ph.D.
Professor, Graduate School of Operational and Information Sciences

Reviewed by:

____
William R. Gates, Ph.D.
Dean, Graduate School of Business & Public Policy

Released by:

____
Karl van Bibber, Ph.D.
Vice President and
Dean of Research

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Abstract

In this quick primer, advanced quantitative risk-based concepts will be introduced—namely, the hands-on applications of Monte Carlo simulation, real options analysis, stochastic forecasting, portfolio optimization, and knowledge value added. These methodologies rely on common metrics and existing techniques (e.g., return on investment, discounted cash flow, cost-based analysis, and so forth), and complement these traditional techniques by pushing the envelope of analytics, not replacing them outright. It is not a complete change of paradigm; and we are not asking the reader to throw out what has been tried and true, but to shift his/her paradigm, to move with the times, and to *improve* upon what has been tried and true. These new methodologies are used in helping make the best possible decisions, allocate budgets, predict outcomes, create portfolios with the highest strategic value and returns on investment, and so forth, where the conditions surrounding these decisions are risky or uncertain. These new techniques can be used to identify, analyze, quantify, value, predict, hedge, mitigate, optimize, allocate, diversify, and manage risk for military options.

Keywords: Real Options Analysis, Portfolio Optimization, Return on Investment, Knowledge Value Added, Integrated Risk Management

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About the Authors

Dr. Johnathan C. Mun is a research professor at the US Naval Postgraduate School (Monterey, California) and teaches executive seminars in quantitative risk analysis, decision sciences, real-options, simulation, portfolio optimization, and other related concepts. He has also researched and consulted on many Department of Defense and Department of Navy projects and is considered a leading world expert on risk analysis and real options analysis. He has authored eight books including *Modeling Risk: Applying Monte Carlo Simulation, Real Options, Optimization, and Forecasting* (Wiley, 2006), *Real Options Analysis: Tools and Techniques,* First and Second Editions (Wiley, 2003 and 2005), *Real Options Analysis Course: Business Cases* (Wiley, 2003), *Applied Risk Analysis: Moving beyond Uncertainty* (Wiley 2003), *Valuing Employee Stock Options* (Wiley, 2004), and others. He is also the founder and CEO of Real Options Valuation, Inc., a consulting, training, and software development firm located in northern California and specializing in strategic real options, financial valuation, Monte Carlo simulation, stochastic forecasting, optimization, and risk analysis. He is the creator of the *Real Options Super Lattice Solver* software, *Risk Simulator* software, and *ESO Valuation* software at the firm, as well as the risk analysis Training DVD; he also holds public seminars on risk analysis and Certified Risk Analyst (CRA) programs. His books and software are being used at top universities around the world (including the Bern Institute in Germany, Chung-Ang University in South Korea, Georgetown University, ITESM in Mexico, Massachusetts Institute of Technology, Naval Postgraduate School, New York University, Stockholm University in Sweden, University of the Andes in Chile, University of Chile, University of Pennsylvania Wharton School, University of York in the United Kingdom, and Edinburgh University in Scotland, among others).

Dr. Mun is also currently a finance and economics professor and has taught courses in financial management, investments, real options, economics, and statistics at the undergraduate and the graduate MBA levels. He is teaching and has taught at universities all over the world, from the US Naval Postgraduate School

(Monterey, California) and University of Applied Sciences (Switzerland and Germany) as full professor, to Golden Gate University (California) and St. Mary's College (California), and has chaired many graduate research thesis committees. He also teaches risk analysis, real options analysis, and risk analysis for managers' public courses, from which participants can obtain the Certified Risk Analyst (CRA) designation upon completion of the week-long program. He was formerly the Vice President of Analytics at Decisioneering, Inc., where he headed up the development of options and financial analytics software products, analytical consulting, training, and technical support, and where he was the creator of the *Real Options Analysis Toolkit* software, the older predecessor of the *Real Options Super Lattice* software. Prior to joining Decisioneering, he was a Consulting Manager and Financial Economist in the Valuation Services and Global Financial Services practice of KPMG Consulting and a Manager with the Economic Consulting Services practice at KPMG LLP. He has extensive experience in econometric modeling, financial analysis, real options, economic analysis, and statistics. During his tenure at Real Options Valuation, Inc., Decisioneering, and at KPMG Consulting, he had taught and consulted on a variety of real options, risk analysis, financial forecasting, project management, and financial valuation issues for over 100 multinational firms (former clients include 3M, Airbus, Boeing, BP, Chevron Texaco, Financial Accounting Standards Board, Fujitsu, GE, Microsoft, Motorola, Pfizer, Timken, US Department of Defense, US Navy, Veritas, and many others). His experience prior to joining KPMG included being Department Head of financial planning and analysis at Viking Inc. of FedEx, performing financial forecasting, economic analysis, and market research. Prior to that, he did financial planning and freelance financial consulting work.

Dr. Mun received his PhD in Finance and Economics from Lehigh University, where his research and academic interests were in the areas of Investment Finance, Econometric Modeling, Financial Options, Corporate Finance, and Microeconomic Theory. He also has an MBA in business administration, an MS in management science, and a BS in Biology and Physics. He is Certified in Financial Risk Management (FRM), Certified in Financial Consulting (CFC), and is Certified in Risk

Analysis (CRA). He is a member of the American Mensa, Phi Beta Kappa Honor Society, and Golden Key Honor Society, as well as several other professional organizations, including the Eastern and Southern Finance Associations, American Economic Association, and Global Association of Risk Professionals. Finally, he has written many academic articles published in the *Journal of the Advances in Quantitative Accounting and Finance,* the *Global Finance Journal,* the *International Financial Review,* the *Journal of Financial Analysis,* the *Journal of Applied Financial Economics,* the *Journal of International Financial Markets, Institutions and Money,* the *Financial Engineering News,* and the *Journal of the Society of Petroleum Engineers.*

Dr. Johnathan C. Mun
Research Professor
Department of Information Science
Graduate School of Operational and Information Sciences
Monterey, CA 93943
Phone: 925-271-4438
Email: jcmun@nps.edu
Web: www.realoptionsvaluation.com

Dr. Tom Housel specializes in valuing intellectual capital, telecommunications, information technology, value-based business process reengineering, and knowledge value measurement in profit and non-profit organizations. He is currently a tenured Full Professor for the Information Sciences (Systems) Department at the Naval Postgraduate School in Monterey, CA. His current research focuses on the use of "Real Options" models in identifying, valuing, maintaining, and exercising options in military decision-making. Prior to joining NPS, he also was a Research Fellow for the Center for Telecommunications Management and Associate Professor at the Marshall School of Business at the University of Southern California. Housel has been the Chief Business Process Engineer for Pacific Bell, where he completed numerous reengineering projects and developed a new method for objectively measuring the value added by reengineering. His last assignment in the corporate world was as the Chief of Consumer Market Research for Telecom Italia in Venice, Italy, where he developed new methods for predicting the adoption rates for new interactive multimedia broadband applications. He is Managing Partner for Business Process Auditors, a firm that specializes in training Big Six consultants, large manufacturing and service companies in the Knowledge Value Added methodology for objectively measuring the return generated by corporate knowledge assets/intellectual capital.

He received his PhD from the University of Utah in 1980. He won the prestigious Society for Information Management award for best paper in the field in 1986. His work on measuring the value of intellectual capital has been featured in a *Fortune* cover story (October 3, 1994) and *Investor's Business Daily*, numerous books, professional periodicals, and academic journals (most recently in the *Journal of Intellectual Capital*, 2 (2005). His latest books include: *Measuring and Managing Knowledge* and *Global Telecommunications Revolution: The Business Perspective* with McGraw-Hill (both in 2001).

Dr. Thomas J. Housel
Department of Information Science
Graduate School of Operational and Information Sciences
Naval Postgraduate School
Monterey, CA 93943-5000
Tel: 831-656-7657
Fax: (831) 656-7657
Email: tjhousel@nps.edu
Web: faculty.nps.edu/tjhousel

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I. Introduction—A Primer on Decision and Risk Analysis: Monte Carlo Simulation, Real Options Analysis, Knowledge Value Added, Forecasting, and Optimization[1]

Since the beginning of recorded history, games of chance have been a popular pastime. Even in Biblical accounts, Roman soldiers cast lots for Christ's robes. In earlier times, chance was something that occurred in nature, and humans were simply subjected to it as a ship is to the capricious tosses of the waves in an ocean. Even up to the time of the Renaissance, the future was thought to be simply a chance occurrence of completely random events and beyond the control of humans. However, with the advent of games of chance, human greed has propelled the study of risk and chance to more closely mirror real-life events. Although these games were initially played with great enthusiasm, no one actually sat down and figured out the odds. Of course, the individual who understood and mastered the concept of chance was bound to be in a better position to profit from such games. It was not until the mid-1600s that the concept of chance was properly studied; the first such serious endeavor can be credited to Blaise Pascal, one of the fathers of the study of choice, chance, and probability. Fortunately for us, after many centuries of mathematical and statistical innovations from pioneers such as Pascal, Bernoulli, Bayes, Gauss, LaPlace, and Fermat, and with the advent of blazing fast computing technology, our modern world of uncertainty can be explained with much more elegance through methodological, rigorous, hands-on applications of risk and uncertainty. Even as recent as two and a half decades ago, computing technology was only in its infancy—running complex and advanced analytical models would have seemed a fantasy; but today, with the assistance of more powerful and enabling software packages, we have the ability to practically apply such techniques with great ease. For this reason, we have chosen to learn from human

[1] This primer is based on Dr. Johnathan Mun's two latest books (*Modeling Risk.* (2006). New York: Wiley; and *Real Options Analysis* (2nd ed.). (2005). New York: Wiley) and is coauthored with Dr. Thomas Housel.

history that with innovation comes the need for a requisite change in human behavior, i.e., the need to apply these new methodologies as the new norm for rigorous risk-benefit analysis.

To the people who lived centuries ago, risk was simply the inevitability of chance occurrence beyond the realm of human control, albeit many phony soothsayers profited from their ability to convincingly profess their clairvoyance by simply stating the obvious or reading the victims' body language and telling them what they wanted to hear. We modern-day humans (ignoring for the moment the occasional seers among us) are still susceptible to risk and uncertainty—even with our fancy technological achievements. We may be able to predict the orbital paths of planets in our solar system with astounding accuracy or the escape velocity required to shoot a man from the Earth to the Moon, or drop a smart bomb within a few feet of its target thousands of miles away, but when it comes to, say, predicting a firm's revenues the following year, we are at a loss. Humans have been struggling with risk our entire existence, but through trial and error, and through the evolution of human knowledge and thought, have devised ways to describe, quantify, hedge, and take advantage of risk.

In the US Military context, risk analysis, real options analysis, and portfolio optimization techniques are enablers of a new way of approaching the problems of estimating return on investment (ROI) and estimating the risk-value of various strategic real options. There are many new Department of Defense (DoD) requirements for using more advanced analytical techniques. For instance, the *Clinger-Cohen Act of 1996* (US Congress, 1996) mandates the use of *portfolio management* for all federal agencies. The Government Accountability Office's *Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making*, Version 1 (1997, February) requires that IT investments apply ROI measures. *DoD Directive 8115.01* issued October 2005 mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments. *DoD Directive 8115.bb* (expected approval in late 2006) implements policy and assigns responsibilities for the management of DoD IT investments as portfolios within the DoD Enterprise—and which defines a portfolio to include outcome performance measures and an expected return on investment. The DoD Risk Management Guidance Defense Acquisition guide book (DoD, DATE) requires that alternatives to the traditional cost estimation need to be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

In this quick primer, advanced quantitative risk-based concepts will be introduced—namely, the hands-on applications of Monte Carlo simulation, real options analysis, stochastic forecasting, portfolio optimization, and knowledge value added. These methodologies rely on common metrics and existing techniques (e.g., return on investment, discounted cash flow, cost-based analysis, and so forth), and complement these traditional techniques by pushing the envelope of analytics, not replacing them outright. It is not a complete change of paradigm; and we are not asking the reader to throw out what has been tried and true, but to shift his/her paradigm, to move with the times, and to *improve* upon what has been tried and true. These new methodologies are used in helping make the best possible decisions, allocate budgets, predict outcomes, create portfolios with the highest strategic value and returns on investment, and so forth, where the conditions surrounding these decisions are risky or uncertain. These new techniques can be used to identify, analyze, quantify, value, predict, hedge, mitigate, optimize, allocate, diversify, and manage risk for military options.

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II. Why Is Risk Important in Making Decisions?

Before we review these advanced techniques, let us first consider why risk is critical when making decisions, and how traditional analyses are inadequate in considering risk in an objective way. Risk is an important part of the decision-making process. For instance, suppose projects are chosen based simply on an evaluation of returns alone or cost alone; clearly the higher-return or lower-cost project will be chosen over lower-return or higher-cost projects.

As mentioned, projects with higher returns will, in most cases, bear higher risks. And, those projects with immediately lower returns would be abandoned. In those cases in which return estimates are wholly derived from cost data (with some form of cost in the numerator and denominator of ROI), the best thing to do is reduce all the costs—i.e., never invest in new projects. In this case, the simplest approach to that is to fire everyone and sell off all the assets. This primary focus on cost reduction results in stifled innovation and crushed creativity. The goal is not simply cost reduction. The real question that must be answered is how cost compares to desired outputs—i.e., "cost compared to what?".

To encourage a focus on improving processes and developing innovative technologies, decision-makers must employ a new way of calculating return on investment that includes a unique numerator. ROI is a basic productivity ratio that requires unique estimates of the numerator (i.e., value, revenue in common units of measurement) and the denominator (i.e., costs, investments in dollars). ROI estimates must be placed within the context of a longer-term view that includes estimates of risk and the ability of management to adapt as they observe the performance of their investments over time. Therefore, instead of relying purely on immediate ROIs or costs, decision-makers should evaluate a project, strategy, process innovation or new technology based on its total strategic value—including returns, costs, strategic options, as well as its risks. Figures 1 and 2 illustrate the managers' errors in judgment when risks are ignored.

Figure 1 lists three *mutually exclusive* projects with their respective costs to implement, expected net returns (net of the costs to implement), and risk levels (all in present values).[2] Clearly, for the budget-constrained decision-maker, the cheaper the project the better, resulting in the selection of Project X. The returns-driven decision-maker will choose Project Y with the highest returns, assuming that budget is not an issue. Project Z will be chosen by the risk-averse decision-maker because it provides the least amount of risk while providing a positive net return. The upshot is that, with three different projects and three different decision-makers, three different decisions will be made. Who is correct and why?

Name of Project	Cost	Returns	Risk
Project X	$50	$50	$25
Project Y	$250	$200	$200
Project Z	$100	$100	$10

Project X for the cost and budget-constrained manager
Project Y for the returns driven and nonresource-constrained manager
Project Z for the risk-adverse manager
Project Z for the smart manager

Figure 1. Why is Risk Important?

Figure 2 shows that Project Z should be chosen. For illustration purposes, we can suppose all three projects are independent and mutually exclusive and that an unlimited number of projects from each category can be chosen, but the budget is constrained at $1,000. Therefore, with this $1,000 budget, 20 Project Xs can be chosen, yielding $1,000 in net returns and $500 risks, and so forth. It is clear from Figure 2 that Project Z is the best project: for the same level of net returns ($1,000), the least amount of risk is undertaken ($100). Another way of viewing this selection is that for each $1 of returns obtained, only $0.1 amount of risk is involved on average, or that for each $1 of risk, $10 in returns are obtained on average. This example illustrates the concept of *bang-for-the-buck* or getting the best value (benefits and costs both considered) with the least amount of risk. An even more blatant example is if there are several different

[2] Risks can be computed many ways, including volatility, standard deviation of lognormal returns, value at risk, and so forth. For more technical details, see Mun (2006).

projects with identical, single-point average net benefit or costs of $10 million each. Without risk analysis, a decision-maker should, in theory, be indifferent in choosing any of the projects. However, with risk analysis, a better decision can be made. For instance, suppose the first project has a 10-percent chance of exceeding $10 million, the second a 15-percent chance, and the third a 55-percent chance. Additional critical information is obtained on the riskiness of the project or strategy, and a better decision can be made.

Looking at bang for the buck, X (2), Y (1), Z (10), Project Z should be chosen–with a $1,000 budget, the following can be obtained:

Project X:	20 Project Xs returning $1,000, with $500 risk
Project Y:	4 Project Xs returning $800, with $800 risk
Project Z:	10 Project Xs returning $1,000, with $100 risk
Project X:	For each $1 return, $0.5 risk is taken
Project Y:	For each $1 return, $1.0 risk is taken
Project Z:	For each $1 return, $0.1 risk is taken
Project X:	For each $1 of risk taken, $2 return is obtained
Project Y:	For each $1 of risk taken, $1 return is obtained
Project Z:	For each $1 of risk taken, $10 return is obtained

Conclusion:
Risk is important. Foregoing risks results in making the wrong decision.

Figure 2. Adding an Element of Risk

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III. From Dealing with Risk the Traditional Way to Monte Carlo Simulation

Military and business leaders have been dealing with risk throughout the history of war and commerce. In most cases, decision-makers have looked at the risks of a particular project, acknowledged their existence, and moved on. Little quantification was performed in the past. In fact, most decision-makers look only to single-point estimates of a project's benefit or profitability. Figure 3 shows an example of a single-point estimate.[3] The estimated net revenue of $30 is simply that—a single point whose probability of occurrence is close to zero.[4] Even in the simple model shown in Figure 3, the effects of interdependencies are ignored. In traditional modeling jargon, we have the problem of *garbage-in, garbage-out* (GIGO). As an example of interdependencies, the units sold are probably negatively correlated to the price of the product, and positively correlated to the average variable cost. Ignoring these effects in a single-point estimate will yield grossly incorrect results. There are numerous interdependencies in military options as well: for example, the many issues in logistics and troop movements—beginning with the manufacturer all the way to the warrior in the field.

In the commercial example below, if the unit sales variable becomes 11 instead of 10, the resulting revenue may not simply be $35. The net revenue may actually decrease due to an increase in variable cost-per-unit while the sale price may actually be slightly lower to accommodate this increase in unit sales. Ignoring these interdependencies will reduce the accuracy of the model.

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[3] We will demonstrate how KVA combined with the traditional Market Comparables valuation method allows for the monetization of benefits (i.e., revenue).

[4] On a continuous basis, the probability of occurrence is the area under a curve, e.g., there is a 90% probability revenues will be between $10 and $11. However, the area under a straight line approaches zero. Therefore, the probability of hitting exactly $10.00 is close to 0.00000001%.

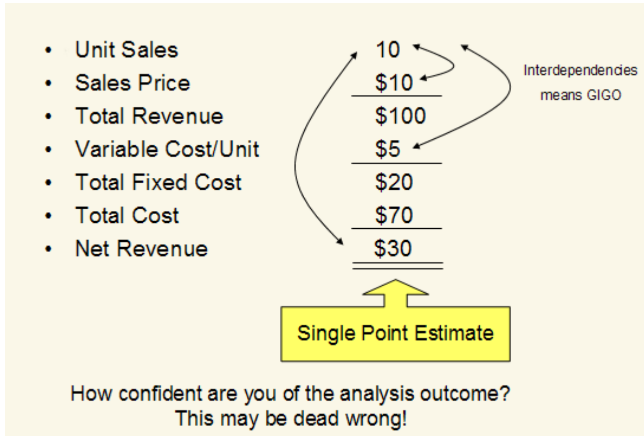

Figure 3. Single-point Estimates

One traditional approach used to deal with risk and uncertainty is the application of scenario analysis. For example, scenario analysis is a central part of the capabilities-based planning approach in widespread use for developing DoD strategies. In the commercial example above, we can imagine three scenarios were generated: the worst-case, nominal-case, and best-case scenarios. When decision-makers apply different values to the unit sales, they obtain the resulting three scenarios' net revenues. As earlier, the problems of interdependencies are not addressed with these common approaches. The net revenues obtained are simply too variable. Not much can be determined from such an analysis.

In the military planning case, the problems are exacerbated by the lack of objective ways to estimate benefits in common units. Without the common-unit benefits analysis, it becomes difficult (if not impossible) to compare the net benefits of various scenarios. In addition, interdependencies must be interpreted in a largely subjective manner—making it impossible to apply powerful mathematical/statistical tools that enable more objective portfolio analysis. The top leaders in the DoD must make judgment calls, analyzing alternatives (often referred to as "trades") to determine the potential benefits and risks of numerous projects and technology investments.

A related approach is to perform *what-if* or *sensitivity* analysis. Each variable is perturbed a prespecified amount (e.g., unit sales is changed ±10%; sales price is changed ±5%, and so forth), and the resulting change in net benefits is captured. This approach is useful for understanding which variables drive or impact the result the most. Performing such analyses by hand or with simple Excel spreadsheets is tedious and provides marginal benefits at best. An approach similar to sensitivity analysis—that has the same goals but uses a more powerful analytic framework—is the use of computer-modeled Monte Carlo simulation and tornado-sensitivity analysis, in which all perturbations, scenarios, and sensitivities are run hundreds of thousands of times automatically.

Therefore, computer-based Monte Carlo simulation, one of the advanced concepts introduced in this paper, can be viewed as simply an extension of the traditional approaches of sensitivity and scenario testing. The critical success drivers of this approach (or the variables that affect the bottom-line variables the most, which at the same time are uncertain) are simulated. In simulation, the interdependencies are accounted for through correlational analysis. The uncertain variables are then simulated tens of thousands of times automatically to emulate all potential permutations and combinations of outcomes. The resulting net revenues-benefits from these simulated potential outcomes are tabulated and analyzed. In essence, in its most basic form, simulation is simply an enhanced version of traditional approaches—such as sensitivity and scenario analysis—but automatically performed thousands of times while accounting for all the dynamic interactions between the simulated variables. The resulting net revenues from simulation, as seen in Figure 4, show that there is a 90-percent probability that the net revenues will fall between \$19.44 and \$41.25, with a 5-percent worst-case scenario of net revenues falling below \$19.44. Rather than having only three scenarios, simulation created 5,000 scenarios, or trials, in which multiple variables are simulated and changing simultaneously (unit sales, sale price, and variable cost-per-unit), while their respective relationships or correlations were maintained.

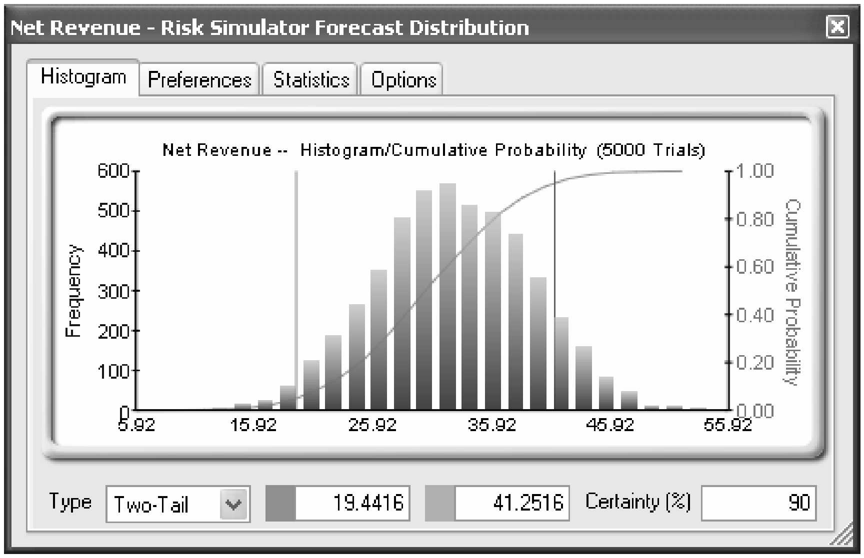

Figure 4. Simulation Results

Monte Carlo simulation, named for the famous gambling capital of Monaco, is a very potent methodology. For the practitioner, simulation opens the door for solving difficult and complex but practical problems with great ease. Perhaps the most famous early use of Monte Carlo simulation was by the Nobel physicist Enrico Fermi (sometimes referred to as the father of the atomic bomb) in 1930, when he used a random method to calculate the properties of the newly discovered neutron. Monte Carlo methods were central to the simulations required for the Manhattan Project, in which the 1950s Monte Carlo simulation was used at Los Alamos for early work relating to the development of the hydrogen bomb, and became popularized in the fields of physics and operations research. The RAND Corporation and the US Air Force were two of the major organizations responsible for funding and disseminating information on Monte Carlo methods during this time, and today there is a wide application of Monte Carlo simulation in many different fields—including engineering, physics, research and development, business, and finance.

Simplistically, Monte Carlo simulation creates artificial futures by generating thousands and even hundreds of thousands of sample paths of outcomes and then analyzes their prevalent characteristics. In practice, Monte Carlo simulation methods are used for risk analysis, risk quantification, sensitivity analysis, and prediction. An alternative to simulation is the use of highly complex, stochastic, closed-form mathematical models. For a high-level decision-maker, taking graduate-level advanced math and statistics courses is just not logical or practical. A well-informed analyst would use all available tools at his or her disposal to obtain the same answer the easiest and most practical way possible. And in all cases, when modeled correctly, Monte Carlo simulation provides similar answers to the more mathematically elegant methods. In addition, there are many real-life applications in which closed-form models do not exist and the only recourse is to apply simulation methods. So, what exactly is Monte Carlo simulation, and how does it work?

Monte Carlo simulation, in its simplest form, is a random-number generator that is useful for forecasting, estimation, and risk analysis. A simulation calculates numerous scenarios of a model by repeatedly picking values from a user-predefined *probability distribution* for the uncertain variables and using those values for the model. As all those scenarios produce associated results in a model, each scenario can have a forecast. Forecasts are events (usually with formulas or functions) that the analysts define as important outputs of the model.

Think of the Monte Carlo simulation approach as picking golf balls out of a large basket repeatedly with replacement. The size and shape of the basket depend on the distributional *input assumption* (e.g., a normal distribution with a mean of 100 and a standard deviation of 10, versus a uniform distribution or a triangular distribution). Some baskets are deeper or more symmetrical than others, allowing certain balls to be pulled out more frequently than others. The number of balls pulled repeatedly depends on the number of *trials* simulated. Each ball is indicative of an event, scenario or condition that can occur. For a large model with multiple and related assumptions, imagine the large model as a very large basket, in which many baby baskets reside. Each baby basket has its own set of colored golf balls that are bouncing around. Sometimes these baby baskets are linked with each other (if there is a *correlation* between the variables), forcing the golf balls to bounce in tandem—whereas in other uncorrelated cases, the balls are bouncing independently of one another. The balls that are picked each time from these interactions within the model (the large basket) are tabulated and recorded, providing a *forecast output* result of the simulation.

IV. Knowledge Value Added Analysis

As the US Military is not in the business of making money, referring to revenues throughout this paper may appear to be a misnomer. For nonprofit organizations, especially in the military, we require KVA, which will provide the required “benefits” or “revenue” proxy estimates to run ROI analysis. ROI is a basic productivity ratio with revenue in the numerator and cost to generate the revenue in the denominator (actually ROI is revenue-cost/cost). KVA generates ROI estimates by developing a market-comparable price-per-common-unit of output, and then multiplying that number by the number of outputs to achieve a total revenue estimate.

KVA is a methodology whose primary purpose is to describe all organizational outputs in common units. This approach provides a means to compare the outputs of all assets (human, machine, information technology) regardless of the aggregated outputs produced. For example, the purpose of a military process may be to gather signal intelligence or plan for a ship alteration. KVA would describe the outputs of both processes in common units, thus making their performance comparable.

KVA measures the value provided by human capital assets and IT assets by analyzing an organization, process or function at the process level. It provides insights into each dollar of IT investment by monetizing the outputs of all assets, including intangible assets (e.g., such as that produced by IT and humans). By capturing the value of knowledge embedded in an organization’s core processes (i.e., employees and IT), KVA identifies the actual cost and revenue of a process, product, or service. Because KVA identifies every process required to produce an aggregated output in terms of the historical prices and costs-per-common-unit of output of those processes, unit costs and unit prices can be calculated. The methodology has been applied in 45 areas within the DoD, from flight scheduling applications to ship maintenance and modernization processes.

As a performance tool, the KVA methodology:

- Compares all processes in terms of relative productivity,
- Allocates revenues and costs to common units of output,
- Measures value added by IT by the outputs it produces, and
- Relates outputs to cost of producing those outputs in common units.

Based on the tenets of complexity theory, KVA assumes that humans and technology in organizations add value by taking inputs and changing them (measured in units of complexity) into outputs through core processes. The amount of change an asset within a process produces can be a measure of value or benefit. The additional assumptions in KVA include:

- A description of all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) allows historical revenue and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required to learn how to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, Units of Learning Time = Common Units of Output (K).
- A common unit of output makes it possible for analysts to compare all outputs in terms of cost-per-unit as well as price-per-unit because KVA allows revenue to be assigned at the sub-organizational level.
- Once cost and revenue streams have been assigned to sub-organizational outputs, normal accounting and financial performance and profitability metrics can be applied (Rodgers & Housel, 2006; Pavlou, Housel, Rodgers & Jansen, 2005; Housel & Kanevsky, 1995).

By describing processes in common units, KVA also permits market-comparable data to be generated, a feature particularly important for non-profits like the US military. By using a market-comparables approach, decision-makers can use data from the commercial sector to estimate price-per-common-unit, allowing for revenue estimates of process outputs for non-profits. This approach also provides a common-units basis00helping decision-makers define benefit streams regardless of the process analyzed.

KVA differs from other nonprofit ROI models because it allows for revenue estimates, enabling the use of traditional accounting, financial performance, and profitability measures at the sub-organizational level. KVA can rank processes by the degree to which they add value to the organization or its outputs. This capability assists decision-makers in identifying how much processes add value. Value is quantified in two key metrics: Return-on-Knowledge (ROK: revenue/cost) and Return-on-Investment (ROI: revenue-investment cost/investment cost). The outputs from a KVA analysis become the input into the ROI models and real options analysis. By tracking the historical volatility of price- and cost-per-unit as well as ROI, it is possible for decision-makers to establish risk (as compared to uncertainty) distributions, which is important if they are to accurately estimate the value of real-options.

The KVA method has been applied to numerous military core processes across the Services. The KVA research has more recently provided a means for simplifying real options analysis for DoD processes. Current KVA research will provide a library of market-comparable price- and cost-per-unit of output estimates. This research will enable a more stable basis for comparisons of performance across core processes. This data also provides a means to establish risk-distribution profiles for integrated risk-analysis approaches such as real options and KVA, which are currently are being linked directly to the Real Options Super Lattice Solver and Risk Simulator software for rapid adjustments to real options valuation projections.

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V. Strategic Real Options Analysis

An important step in performing real options analysis is the application of Monte Carlo simulation. By applying Monte Carlo simulation to simultaneously change all critical inputs in a correlated manner within a model, decision-makers can identify, quantify, and analyze risk.[5] The question then is, what next? Simply quantifying risk is useless unless one can manage it, reduce it, control it, hedge it, or mitigate it. This is where strategic real options analysis comes in. We can think of real options as a strategic road map for making decisions.

Suppose you are driving from point A to point B, and you only have or know one way to get there, a straight route. Further suppose that there is a significant amount of *uncertainty* as to what traffic conditions are like further down the road, and you *risk* being stuck in traffic, and there is a 50% chance that will occur. Simulation will provide you the 50% figure. It is important to realize that half the time you will get stuck in traffic, but the question now is, so what? Especially if you have to get to point B no matter what. However, if you had several alternate routes to get to point B, you can still drive the straight route; but, if you hit traffic, you can make a left, right, or U-turn to get around congestion—mitigating the risk, and getting you to point B faster and safer. That is, you have *options*. So, how much is such a strategic road map or global positioning satellite map worth to you? In military situations with high risk, real options analysis helps create strategies to mitigate these risks. In fact, businesses and the military have been doing real options for hundreds of years without fully realizing it. For instance, in the military, we call it *courses of action* or *analysis of alternatives:* do we take Hill A so that it provides us the option and ability to take Hill B and Valley C, or should we take Valley C? Or do we avoid taking Valley C altogether, and so forth. A piece that is missing is the more formal structure (and subsequent analytics) that real options analysis provides.

[5] The outcomes from a Monte Carlo simulation include probabilities and various risk statistics that can be used to make better decisions.

Using real options analysis, we can quantify and value each strategic pathway and frame strategies that will hedge or mitigate, and sometimes take advantage of risk.

In the past, corporate investment decisions were cut-and-dried: buy a new machine that is more efficient; make more products costing a certain amount, and if the benefits outweigh the costs, execute the investment. Hire a larger pool of sales associates; expand the current geographical area, and if the marginal increase in forecast sales revenues exceeds the additional salary and implementation costs, start hiring. Need a new manufacturing plant? Show that the construction costs can be recouped quickly and easily by the increase in revenues it will generate through new and more improved products, and approve the initiative. However, real-life conditions are a lot more complicated. Your firm decides to go with an e-commerce strategy, but multiple strategic paths exist. Which path do you choose? What are the options that you have? If you choose the wrong path, how do you get back on the right track? How do you value and prioritize the paths that exist? You are a venture capitalist firm with multiple business plans to consider. How do you value a start-up firm with no proven track record? How do you structure a mutually beneficial investment deal? What is the optimal timing to a second or third round of financing?

Real options is useful not only in valuing a firm through its strategic business options, but also as a strategic business tool in capital investment acquisition decisions. For instance, should the military invest millions in a new open architecture initiative, and if so, what are the values of the various strategies such an investment would enable, and how do we proceed? How does the military choose among several seemingly cashless, costly, and unprofitable information-technology infrastructure projects? Should it indulge its billions in a risky research-and-development initiative? The consequences of a wrong decision can be disastrous; lives could be at stake. In a traditional analysis, these questions cannot be answered with any certainty. In fact, some of the answers generated through the use of the traditional analysis are flawed because the model assumes a static, one-time decision-making process. Yet, the real options approach takes into consideration the strategic options certain projects create under uncertainty and a decision-maker's flexibility in exercising or abandoning these options at different points in time, when the level of uncertainty has decreased or has become known over time.

The real options approach incorporates a learning model that helps the decision-maker make better and more-informed strategic decisions when some levels of uncertainty are resolved through the passage of time, actions, and events. The use of the KVA methodology to monitor the performance of given options—and the adjustments to real options as leaders learn more from the execution of given options—provide an integrated methodology to help military leaders hedge their bets while taking advantage of new opportunities over time. Traditional analysis assumes a static investment decision and assumes that strategic decisions are made initially with no recourse to choose other pathways or options in the future. Real options analysis can be used to frame strategies to mitigate risk, maximize value and find the optimal strategy pathway to pursue. It can likewise generate options to enhance the value of the project while managing risks. Imagine real options as your guide when you are navigating through unfamiliar territory; it would provide road signs at every turn to guide you in making the best and most-informed driving decisions. This is the essence of real-options. Figure 5 illustrates a very basic real options framing exercise—clearly more complex situations can be set up. From the options that are framed, Monte Carlo simulation and stochastic forecasting (coupled with traditional techniques) are applied. Then, real options analytics are applied to solve and value each strategic pathway; an informed decision can then be made.[6]

As mentioned preciously, real options analysis can generate options to enhance the value of the project while managing risks. Sample capabilities include the option to expand, contract, abandon, or utilize sequential compound options (phased stage-gate options, wait-and-defer investment options, proof-of-concept stages, milestone development and research-and-development initiatives). Some sample applications in

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[6] The pathways can be valued using partial differential closed-form equations, lattices, and simulation. The Real Options SLS software by Real Options Valuation, Inc., (www.realoptionsvaluation.com) is used to value these options with great ease.

the military arena include applications of real options to acquisitions, Spiral Development and various organizational configurations, as well as the importance of how Integrated and Open Architectures become real options multipliers. Under *OMB Circular A-76*, comparisons using real options analysis could be applied to enhance outsourcing comparisons between the Government's Most Efficient Organization (MEO) and private-sector alternatives (OMB, DATE). Real options can be used throughout JCIDS requirements generation and the Defense Acquisition System, e.g., DOTMLPF vs. New Program/Service solution, Joint Integration, Analysis of Material Alternatives (AMA), Analysis of Alternatives (AoA) and Spiral Development. Many other applications exist in military decision analyses and portfolios.

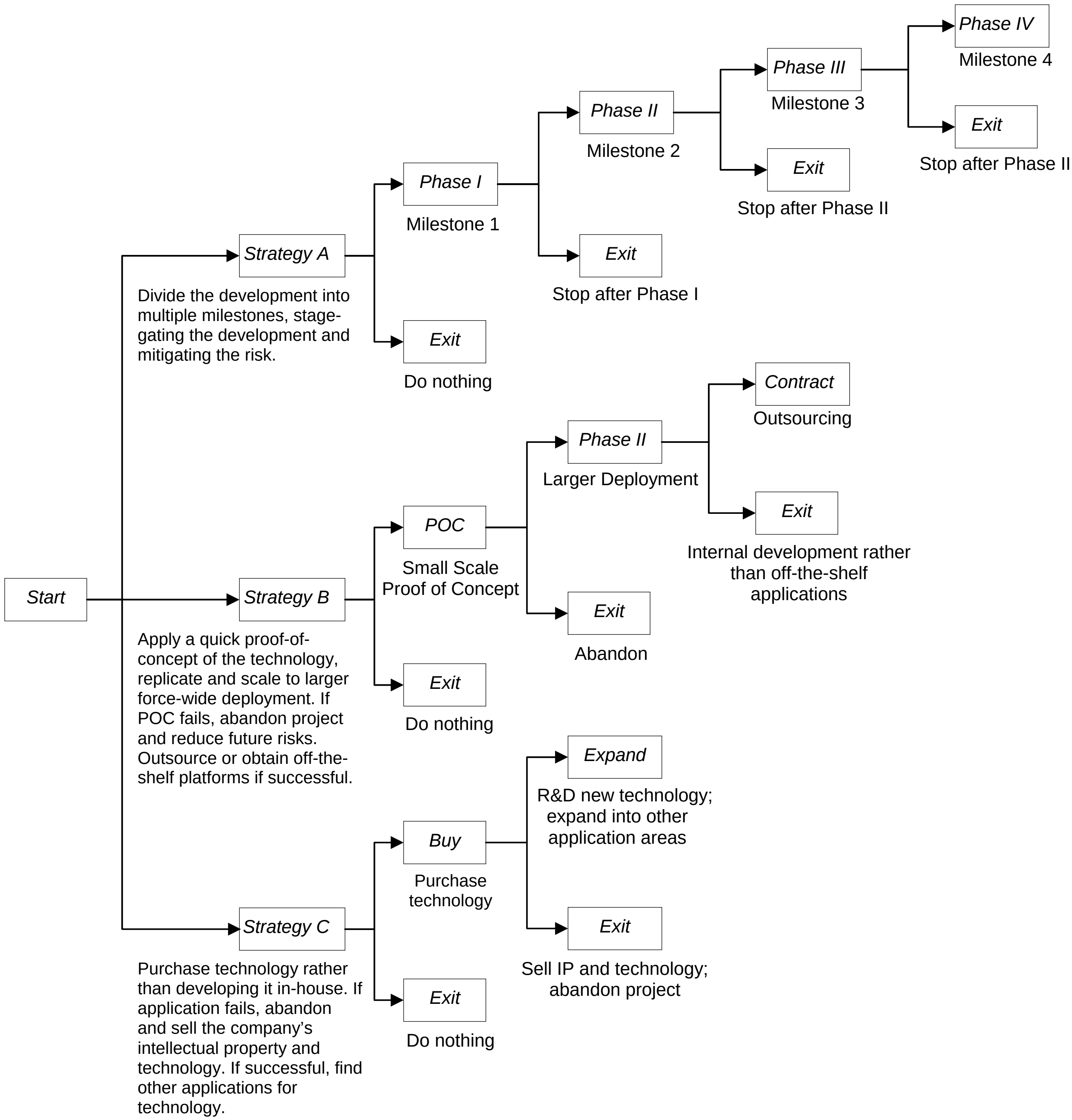

Figure 5. Example: Real Options Framing

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VI. Portfolio Optimization

In most decisions, there are variables over which leadership has control, such as how much to establish supply lines, modernize a ship, use network centricity to gather intelligence, etc. Similarly, business leaders have options in what they charge for a product or how much to invest in a project or which projects they should choose in a portfolio when they are constrained by budgets or resources. These decisions could also include allocating financial resources, building or expanding facilities, managing inventories, and determining product-mix strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical or even impossible. These controlled variables are called decision variables. Finding the optimal values for decision variables can make the difference between decision-makers reaching an important goal and their missing that goal. An optimization model can provide valuable assistance in incorporating relevant variables when analyzing decisions and finding the best solutions for making decisions. Optimization models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., best way to deploy troops, build ships, which projects to execute) in every conceivable way such that the objective is maximized (e.g., strategic value, enemy assets destroyed, return on investment) or minimized (e.g., risk and costs) while still satisfying the constraints (e.g., time, budget, and resources).

Obtaining optimal values generally requires that decision-makers search in an iterative or ad hoc fashion. This search involves running one iteration for an initial set of values, analyzing the results, changing one or more values, rerunning the model, and repeating the process until they find a satisfactory solution. This process can be very tedious and time consuming even for small models, and often it is not clear how to adjust the values from one iteration to the next. A more rigorous method systematically enumerates all possible alternatives. This approach guarantees optimal solutions if the model is correctly specified. Suppose that an optimization model depends on only two decision variables. If each variable has 10 possible values, trying each combination requires 100 iterations (10^2 alternatives). If each iteration is takes a very short amount of time (e.g., 2 seconds), then the entire process could be done in approximately three minutes of computer time. However, instead of two decision variables, consider six; then consider that trying all combinations requires 1,000,000 iterations (10^6 alternatives). It is easily possible for complete enumeration to take many years to carry out. Therefore, optimization has always been a fantasy until now; with the advent of sophisticated software and computing power, coupled with smart heuristics and algorithms, such analyses can be done within minutes.

Figures 6 to 8 illustrate a sample portfolio analysis. In the first case of this analysis, there are 20 total projects to choose from (if all projects were executed, it would cost $10.2 billion). Each project has its own returns on investment or benefits metric, cost, strategic ranking, comprehensive, tactical and total military scores (these were obtained from field commanders through the Delphi method to elicit their thoughts about how strategic a particular project or initiative will be, and so forth). The constraints are full-time equivalence resources, budget, and strategic score. In other words, there are 20 projects or initiatives to choose from, and we want to select the top 10—subject to having enough money to pay for them, the people to do the work, and, yet, be the most strategic portfolio possible.[7] All the while, Monte Carlo simulation, real options, and forecasting methodologies are applied in the optimization model (e.g., the values for each project are shown in Figure 6 and are linked from their own large models with simulation and forecasting methodologies applied, and the best strategy for each project is chosen using real options analysis. Or, perhaps the projects shown are nested within one another. For instance, you cannot exercise Project 2 unless you execute Project 1, but you can only exercise Project 1 without having to do Project 2, and so forth). The results are shown in Figure 6.

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[7] There are 2 x 10^{18} possible permutations for this problem, and if tested by hand, would take years to complete. Using *Risk Simulator*, the problem is solved in about 5 seconds, or several minutes if Monte Carlo simulation and real options are incorporated in the analysis.

Figure 7 shows the optimization process done in series, with some of the constraints relaxed. For instance, what would be the best portfolio and the strategic outcome if a budget of $3.8 billion was imposed? What if it was increased to $4.8 billion, $5.8 billion, and so forth? The efficient frontiers depicted in Figure 7 illustrate the best combination and permutation of projects in the optimal portfolio. Each point on the frontier is a portfolio of various combinations of projects that provides the best allocation possible given the requirements and constraints. Finally, Figure 8 shows the top 10 projects that were chosen and how the total budget is best and most optimally allocated to provide the best and most well-balanced portfolio.

Project Name	ENPV	Benefits	Cost	Strategy Ranking	Return to Rank Ratio	Profitability Index	Selection	Comprehensive Score	Tactical Score	FTE Resources	Military Score
Project 1	$458.00	$150.76	$1,732.44	1.20	381.67	1.09	0	8.10	2.31	1.20	1.98
Project 2	$1,954.00	$245.00	$859.00	9.80	199.39	1.29	1	1.27	4.83	2.50	1.76
Project 3	$1,599.00	$458.00	$1,845.00	9.70	164.85	1.25	0	9.88	4.75	3.60	2.77
Project 4	$2,251.00	$529.00	$1,645.00	4.50	500.22	1.32	0	8.83	1.61	4.50	2.07
Project 5	$849.00	$564.00	$458.00	10.90	77.89	2.23	0	5.02	6.25	5.50	2.94
Project 6	$758.00	$135.00	$52.00	7.40	102.43	3.60	1	3.64	5.79	9.20	3.26
Project 7	$2,845.00	$311.00	$758.00	19.80	143.69	1.41	1	5.27	6.47	12.50	4.04
Project 8	$1,235.00	$754.00	$115.00	7.50	164.67	7.56	1	9.80	7.16	5.30	3.63
Project 9	$1,945.00	$198.00	$125.00	10.80	180.09	2.58	1	5.68	2.39	6.30	2.16
Project 10	$2,250.00	$785.00	$458.00	8.50	264.71	2.71	1	8.29	4.41	4.50	2.67
Project 11	$549.00	$35.00	$45.00	4.80	114.38	1.78	0	7.52	4.65	4.90	2.75
Project 12	$525.00	$75.00	$105.00	5.90	88.98	1.71	0	5.54	5.09	5.20	2.69
Project 13	$516.00	$451.00	$48.00	2.80	184.29	10.40	0	2.51	2.17	4.60	1.66
Project 14	$499.00	$458.00	$351.00	9.40	53.09	2.30	1	9.41	9.49	9.90	4.85
Project 15	$859.00	$125.00	$421.00	6.50	132.15	1.30	1	6.91	9.62	7.20	4.25
Project 16	$884.00	$458.00	$124.00	3.90	226.67	4.69	1	7.06	9.98	7.50	4.46
Project 17	$956.00	$124.00	$521.00	15.40	62.08	1.24	1	1.25	2.50	8.60	2.07
Project 18	$854.00	$164.00	$512.00	21.00	40.67	1.32	0	3.09	2.90	4.30	1.70
Project 19	$195.00	$45.00	$5.00	1.20	162.50	10.00	0	5.25	1.22	4.10	1.86
Project 20	$210.00	$85.00	$21.00	1.00	210.00	5.05	0	2.01	4.06	5.20	2.50
Total	$14,185.00		$3,784.00	99.00			10	**58.58**	**62.64**	73.50	**33.15**
Profit/Rank	$143.28										
Profit*Score	$470,235.60	Maximize	< =$3800	< =100			x <=10			<=80	

Figure 6. Portfolio Optimization and Allocation

Budget	Military Score	Tactical Score	Comprehensive Score	Allowed Projects	ROI-RANK Objective
$3,800.00	33.15	62.64	58.58	10	$470,235.60
$4,800.00	36.33	68.85	66.86	11	$521,645.92
$5,800.00	38.40	70.46	75.69	12	$623,557.79
$6,800.00	39.94	72.14	82.31	13	$659,947.99
$7,800.00	39.76	70.05	86.54	14	$676,279.81

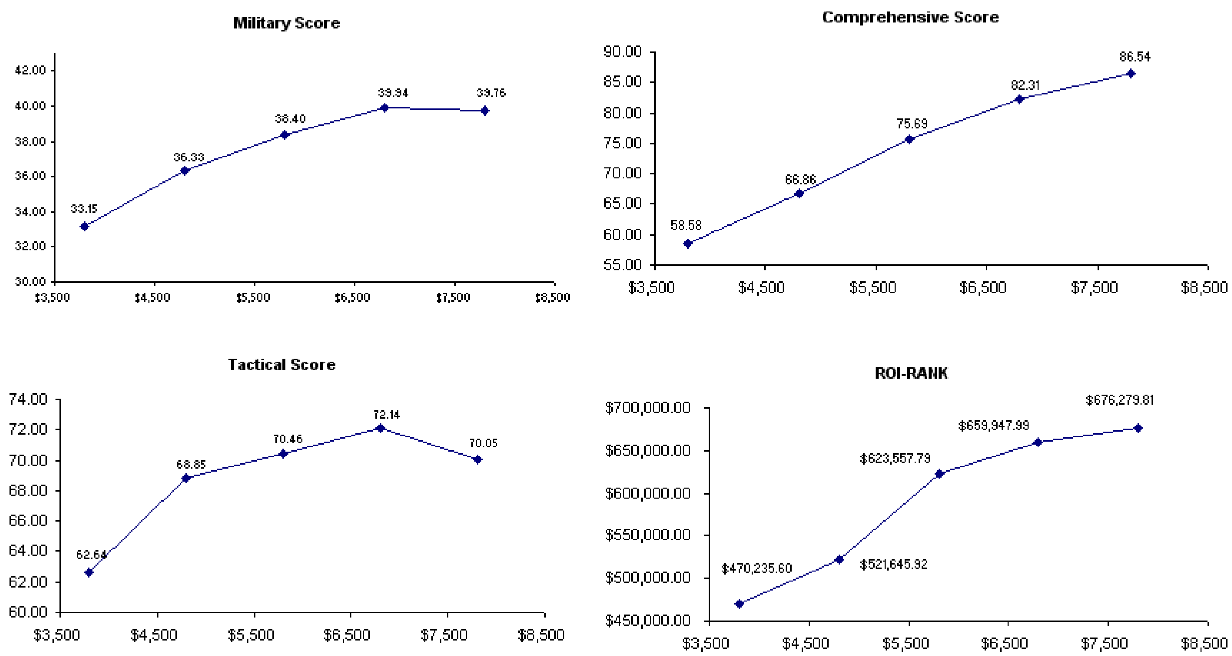

Figure 7. Efficient Frontiers of Portfolios

ASSET ALLOCATION OPTIMIZATION MODEL

Asset Class Description	Annualized Returns	Volatility Risk	Allocation Weights	Required Minimum Allocation	Required Maximum Allocation	Return to Risk Ratio	Returns Ranking (Hi-Lo)	Risk Ranking (Lo-Hi)	Return to Risk Ranking (Hi-Lo)	Allocation Ranking (Hi-Lo)
Selected Project 1	10.50%	12.38%	11.10%	5.00%	35.00%	0.8483	9	2	7	4
Selected Project 2	11.12%	16.36%	6.74%	5.00%	35.00%	0.6799	7	8	10	10
Selected Project 3	11.77%	15.81%	7.63%	5.00%	35.00%	0.7445	6	7	9	9
Selected Project 4	10.77%	12.33%	11.49%	5.00%	35.00%	0.8738	8	1	5	3
Selected Project 5	13.49%	13.35%	12.26%	5.00%	35.00%	1.0102	5	4	2	2
Selected Project 6	14.24%	14.53%	10.94%	5.00%	35.00%	0.9800	3	6	3	5
Selected Project 7	15.60%	14.30%	12.36%	5.00%	35.00%	1.0908	1	5	1	1
Selected Project 8	14.95%	16.64%	8.75%	5.00%	35.00%	0.8983	2	10	4	7
Selected Project 9	14.15%	16.56%	8.36%	5.00%	35.00%	0.8545	4	9	6	8
Selected Project 10	10.08%	12.55%	10.37%	5.00%	35.00%	0.8027	10	3	8	6
Portfolio Total	*12.7270%*	*4.54%*	*100.00%*							
Return to Risk Ratio	*2.8021*									

Figure 8. Portfolio Optimization (Continuous Allocation of Funds)

VII. Integrated Risk Analysis Framework

We are now able to put all the pieces together into an *integrated risk analysis framework* and see how these different techniques are related in a risk-analysis and risk-management context. This framework comprises eight distinct phases of a successful and comprehensive risk-analysis implementation—going from a qualitative management screening process to creating clear and concise reports for management. The process was developed by the author based on previous successful implementations of risk analysis, forecasting, real options, KVA cash-flow estimates, valuation, and optimization projects both in the consulting arena and in industry-specific problems. These phases can be performed either in isolation or together in sequence for a more robust integrated analysis.

Figure 9 shows the integrated risk analysis process up close. We can segregate the process into the following eight simple steps:

1. Qualitative management screening
2. Time-series and regression forecasting
3. Base case KVA and net-present-value analysis
4. Monte Carlo simulation
5. Real options problem framing
6. Real options modeling and analysis
7. Portfolio and resource optimization
8. Reporting and update analysis

A. Qualitative Management Screening

Qualitative management screening is the first step in any integrated risk-analysis process. Decision-makers have to decide which projects, assets, initiatives, or strategies are viable for further analysis, in accordance with the organization's mission, vision, goal, or overall business strategy. The organization's mission, vision, goal, or overall business strategy may include strategies and tactics, competitive advantage, technical, acquisition, growth, synergistic or global threat issues. That is, the initial list of projects should be qualified in terms of meeting the leadership's agenda. Often the most valuable insight is created as leaders frame the complete problem to be resolved. This is the stage of the risk-analysis process in which the various risks to the organization are identified and fleshed out.

B. Time-Series and Regression Forecasting

The next stage is for decision-makers to then forecast the using time-series analysis, stochastic forecasting, or multivariate regression analysis if historical or comparable data exist. Otherwise, other qualitative forecasting methods may be used (subjective guesses, growth-rate assumptions, expert opinions, Delphi method, and so forth).[8]

C. Base Case KVA and Net Present Value Analysis

For each project that passes the initial qualitative screens, a KVA-based discounted cash flow model is created. This model serves as the base case analysis from which decision-makers calculate a net present value and an ROI for each project using the forecasted values in the previous step. This step also applies if only a single project is under evaluation. Decision-makers can calculate this net present value using the traditional approach utilizing the forecast revenues and costs and discounting the net of these revenues and costs at an appropriate risk-adjusted rate. In this step, an organization's leaders also generate the ROI and other financial metrics.

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[8] See Chapters 8 and 9 of *Modeling Risk* (2006) by Dr. Johnathan Mun for details on forecasting and using the author's *Risk Simulator* software to run time-series, extrapolation, stochastic process, ARIMA, and regression forecasts.

D. Monte Carlo Simulation[9]

Because the static discounted cash flow produces only a single-point estimate result, there is often little confidence in its accuracy given that future events that affect forecast cash flows are highly uncertain. To better estimate the actual value of a particular project, decision-makers should employ Monte Carlo simulation next. Usually, a sensitivity analysis is first performed on the discounted cash-flow model; that is, setting the net present value or ROI as the resulting variable, we can change each of its precedent variables and note the change in the resulting variable. Precedent variables include revenues, costs, tax rates, discount rates, capital expenditures, depreciation, and so forth, which ultimately flow through the model to affect the net present value or ROI figure. By tracing back all these precedent variables, we can change each one by a preset amount and see the effect on the resulting net present value. A graphical representation can then be created in Risk Simulator (which is often called a tornado chart because of its shape) in which the most sensitive precedent variables are listed first, in descending order of magnitude. Armed with this information, the analyst can then decide which key variables are highly uncertain in the future and which are deterministic. The uncertain key variables that drive the net present value (and, hence, the decision) are called critical success drivers. These critical success drivers are prime candidates for Monte Carlo simulation. Because some of these critical success drivers may be correlated, a correlated and multidimensional Monte Carlo simulation may be required. Typically, these correlations can be obtained through historical data. Running correlated simulations provides a much closer approximation to the variables' real-life behaviors.

[9] See Chapters 4 and 5 of *Modeling Risk* (2006) by Dr. Johnathan Mun for details on running Monte Carlo simulation using the author's *Risk Simulator* software.

E. Real Options Problem Framing[10]

The question now is that after quantifying risks in the previous step, what should a decision-maker do next? The risk information obtained somehow needs to be converted into *actionable intelligence*. Just because risk has been quantified to be such and such using Monte Carlo simulation, so what? What do we do about it? The answer is to use real options analysis to hedge these risks, to value these risks, and to position the organization to take advantage of the risks. The first step in real options is to generate a strategic map through the process of framing the problem. Based on the overall problem identification occurring during the initial qualitative management-screening process, certain strategic optionalities would have become apparent for each particular project. The strategic optionalities may include (among other things), the option to expand, contract, abandon, switch, choose, and so forth. Based on the identification of strategic optionalities that exist for each project or at each stage of the project, the analyst can then choose from a list of options to analyze in more detail. Real options are added to the projects to hedge downside risks and to take advantage of upside swings.

F. Real Options Modeling and Analysis

Through the use of Monte Carlo simulation, the resulting stochastic discounted cash-flow model will have a distribution of values. Thus, simulation models, analyzes, and quantifies the various risks and uncertainties of each project. The result is a distribution of the NPVs and the project's volatility. In real options, we assume that the underlying variable is the future profitability of the project, which is the future cash-flow series. An implied volatility of the future free cash flow or underlying variable can be calculated through the results of a Monte Carlo simulation previously performed. Usually, the volatility is measured as the standard deviation of the logarithmic returns on the free cash flow stream. In addition, the present value of future cash flows for the base case discounted cash flow model is used as the initial underlying asset value in

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[10] See *Real Options Analysis (2nd ed.): Tools and Techniques* (2005) by Dr. Johnathan Mun for more technical details on framing and solving real options problems.

real options modeling. Using these inputs, real options analysis is performed to obtain the projects' strategic option values.

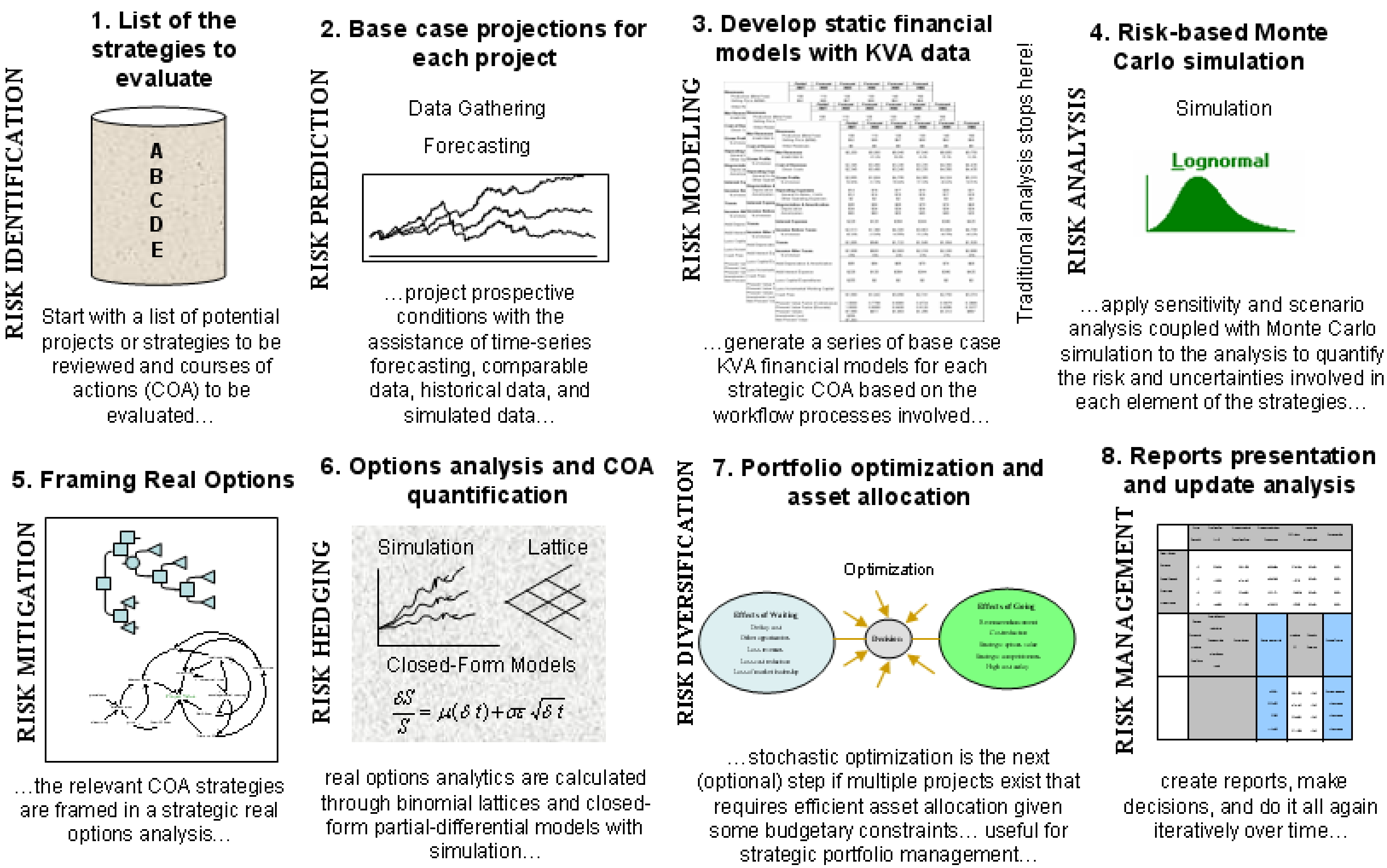

Figure 9. Integrated Risk Analysis Process

G. Portfolio and Resource Optimization[11]

Portfolio optimization is an optional step in the analysis. If the analysis is done on multiple projects, decision-makers should view the results as a portfolio of rolled-up projects because the projects are, in most cases, correlated with one another, and viewing them individually will not present the true picture. As organizations do not only have single projects, portfolio optimization is crucial. Given that certain projects are related to others, there are opportunities for hedging and diversifying risks through a portfolio. Because firms have limited budgets, have time and resource constraints, while at the same time have requirements for certain overall levels of returns, risk tolerances, and so forth, portfolio optimization takes into account all these to create an optimal portfolio mix. The analysis will provide the optimal allocation of investments across multiple projects.

H. Reporting and Update Analysis

The analysis is not complete until reports can be generated. Not only are results presented, but the process should also be shown. Clear, concise, and precise explanations transform a difficult black-box set of analytics into transparent steps. Decision-makers will never accept results coming from black boxes if they do not understand where the assumptions or data originate and what types of mathematical or analytical massaging take place. Risk analysis assumes that the future is uncertain and that decision-makers have the right to make midcourse corrections when these uncertainties become resolved or risks become known; the analysis is usually done ahead of time and, thus, ahead of such uncertainty and risks. Therefore, when these risks become known over the passage of time, actions, and events, the analysis should be revisited to incorporate the decisions made or revise any input assumptions. Sometimes, for long-horizon projects, decision-makers should perform several iterations of the real options analysis, where future iterations are updated with the latest data and assumptions. Understanding the

[11] See Chapters 10 and 11 of *Modeling Risk* (2006) by Dr. Johnathan Mun for details on using *Risk Simulator* to perform portfolio optimization.

steps required to undertake an integrated risk analysis is important because it provides insight not only into the methodology itself but also into how it evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

VIII. Training for the Integrated Methodology

The training for risk analysis, simulation, forecasting, optimization, KVA, and real options is provided in a week-long, 40-hour, intensive course. This course is designed to introduce students to the tools and techniques used to generate risk-based simulation, KVA, portfolio optimization, and real options valuation methods. The use of real-life military and business case studies provide the students with near-real-life experience in using the tools and methods. The students who pass the test at the conclusion of the course, during the second half of the last day, receive a Certified Risk Analyst (CRA) certification from the American Academy of Financial Management. While the course will not make students completely proficient, it is the first step in building a level of proficiency. The software companies and professors Housel and Mun provide ongoing support for those engaged in KVA and real options analysis over time. The focus of these ongoing support efforts is to build a proficiency in the analysts who will do this analysis throughout the DoD. It also provides a means for the authors of this work to continually build the database of risk analysis, real options, KVA ROI models, and cash-flow estimates, as well as the library of cases for future education and training classes.[12]

[12] The cost basis for the class is determined by the number of students (no more than 20 per class), facilities (laptops for all students and classroom), and location (if the class is held at NPS a number of these factors can be mitigated based on availability of facilities). Online training is also available.

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IX. Conclusion

Hopefully it has now become evident that the DoD leadership can take advantage of more advanced analytical procedures for making strategic investment decisions and for managing portfolios of projects than available previously. In the past, due to the lack of technological maturity, this would have been extremely difficult; hence, businesses and the government had to resort to experience and managing by gut feel. Now, with the assistance of technology and more mature methodologies, financial leaders have every reason to take the analysis a step further. Corporations like 3M, Airbus, AT&T, Boeing, BP, Chevron, Johnson & Johnson, Motorola, and many others have already been successfully using these techniques for years. Hence, the military can follow suit. The relevant software applications, books, case studies, and public seminars have been created, and case studies have already been developed for the US Navy.[13] The only barrier to implementation, simply put, is the lack of exposure to the potential benefits of the methods. Many in the military have not seen or even heard of these new concepts. Hopefully, this primer, if it is successful, serves to reveal the potential benefits of these analytical techniques and tools that can complement what leadership is currently doing. In order to be ready for the challenges of the 21st century and to create a highly effective and flexible military force, strategic real options, KVA, and risk analyses are available to aid leadership with critical decision-making. Real options and KVA are tools that will help ensure maximum strategic flexibility and analysis of alternatives where risks must be considered.

[13] See www.realoptionsvaluation.com (Download site) for more details on the software applications *Risk Simulator* and *Real Options SLS* as well as sample case studies, videos, sample models, and training seminars (e.g., the 4-day Certified Risk Analyst public seminars cover all the methodologies outlined in this primer and more).

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